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The Effects of Plains Pocket Gophers on Two Varieties of Alfalfa

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THE EFFECTS OF PLAINS POCKET GOPHERS
ON TWO VARIETIES OF ALFALFA

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THE EFFECTS OF PLAINS POCKET GOPHERS ON TWO VARIETIES OF ALFALFA

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Pocket gophers (Geomyidae) reduce alfalfa (*Medicago sativa*) yields by their feeding and burrowing behaviors. To determine the success of cultural control of gopher damage, I examined the effects of plains pocket gophers (*Geomys bursarius*) on the yield and forage quality of 2 varieties of alfalfa, Wrangler and Spredor 2. Wrangler has higher yields than Spredor 2, but Spredor 2 has a creeping root that sends up new shoots when damaged. I predicted that gopher activity would stimulate shoot production in Spredor 2, compensating for loss of yield to gophers. I also predicted that Spredor 2's creeping root system would maintain its ability to absorb nutrients in the presence of gophers. Thus, Spredor 2 may be suitable as a cultural control of gopher damage. The presence of gophers reduced yields of Wrangler 19% ($p = 0.01$), but not Spredor 2 ($p = 0.30$). Root biomass was not affected by the presence of gophers ($p \geq 0.46$). Spredor 2 density decreased 15% when gophers were present for less than 1 year ($p = 0.09$) and 11% when gophers were present for 1 to 2 years ($p = 0.04$), while Wrangler density decreased 10% when gophers were present for 1 to 2 years ($p = 0.05$). Weed biomass increased 390% ($p = 0.03$) and 256% ($p = 0.08$) in Wrangler and Spredor 2, respectively, when gophers were present for 1 to 2 years. Presence of gophers did not affect acid detergent fiber, neutral detergent fiber, relative feed value, protein, Al, Fe, P, S, or Si of either variety ($p \geq 0.12$). In Spredor 2, Cl increased 31% ($p = 0.05$) and Cu, Mn, and Zn decreased 15% ($p = 0.09$), 16% ($p = 0.08$), and 13% ($p = 0.0004$), respectively, on plots with gophers. In Wrangler, Cu, Mg, Mn, and Zn decreased 19% ($p = 0.05$), 14% ($p = 0.03$), 19% ($p = 0.04$), and 13% ($p = 0.002$), respectively, on plots with gophers. Where gophers were present for 1

to 2 years, Ca increased 7% ($p = 0.01$) in Spredor 2, but decreased 15% ($p = 0.002$) in Wrangler. The variables that I used to check forage quality indicated that there were no substantial differences between varieties or attributable to belowground herbivory by pocket gophers. As measured by yields, Spredor 2 appeared to withstand gopher damage better than Wrangler.

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Table of Contents

	Page
Abstract	ii
Acknowledgments	iv
Table of Contents	v
List of Figures and Tables	vii
List of Appendices	viii
Introduction	1
Literature Review	3
Literature Cited	12
Chapter 1: The Effects of Plains Pocket Gophers (*Geomys bursarius*)	
on Alfalfa (*Medicago sativa*) and Weed Biomass	17
Abstract	18
Introduction	19
Study Area	21
Methods	21
Results and Discussion	23
Conclusion	27
Literature Cited	28
Chapter 2: The Effects of Plains Pocket Gophers (*Geomys bursarius*)	
on Alfalfa (*Medicago sativa*) Forage Quality	37
Abstract	38
Introduction	39
Study Area	41
Methods	42
Results and Discussion	44

	Page
Conclusion	49
Literature Cited	50
Appendix A	62
Appendix B	63

List of Figures and Tables

Chapter 1 Page

Figure 1. Study site at the University of Nebraska Agricultural Research and Development Center, Saunders County, Nebraska. 31

Table 1a. Yields (kg/ha) of Wrangler (W) and Spredor 2 (S) alfalfa on 9 blocks without gophers in 1995 and 1996. 32

Table 1b. Yields (kg/ha) of Wrangler (W) and Spredor 2 (S) alfalfa on 4 blocks of control plots (C) and plots with gophers (G). 32

Table 2. Root biomass (g/l) of Wrangler (W) and Spredor 2 (S) alfalfa in control plots (C) and plots with gophers (G) in 1995 and 1996. 33

Table 3a. Alfalfa density/m^2 of Wrangler (W) and Spredor 2 (S) in control plots (C) and plots inhabited by gophers (G) for less than 1 year in1995 and 1996. 34

Table 3b. Alfalfa density/m^2 of Wrangler (W) and Spredor 2 (S) in control plots (C) and plots inhabited by gophers (G) for 1 to 2 years in 1996. 34

Table 4a. Weed biomass (kg/ha) in Wrangler (W) and Spredor 2 (S) alfalfa on 9 blocks without gophers in 1995 and 1996. 35

Table 4b. Weed biomass (kg/ha) in Wrangler (W) and Spredor 2 (S) alfalfa in control plots (C) and plots inhabited by gophers (G) for less than 1 year in 1995 and 1996. 35

Table 4c. Weed biomass (kg/ha) in Wrangler (W) and Spredor 2 (S) alfalfa in control plots (C) and plots inhabited by gophers (G) for 1 to 2 years in 1996. 36

Chapter 2

Figure 1. Study site at the University of Nebraska Agricultural Research and Development Center, Saunders County, Nebraska. 55

Table 1. Ranges of various forage quality factors and elements expected for alfalfa (Natl. Res. Counc. 1971, Martin and Matocha 1973, Mader and Rush 1984, Howarth 1988, Anderson and Mader 1994). 56

Table 2a. Acid detergent fiber (%) of Wrangler (W) and Spredor 2 (S) alfalfa in control plots (C) and plots with gophers (G). 57

Table 2b. Acid detergent fiber (%) of Wrangler (W) and Spredor 2 (S) alfalfa in control (C) plots and plots with gophers (G), by harvest. 57

Table 3a. Neutral detergent fiber (%) of Wrangler (W) and Spredor 2 (S) alfalfa in control plots (C) and plots with gophers (G). 58

Table 3b. Neutral detergent fiber (%) of Wrangler (W) and Spredor 2 (S) alfalfa in control (C) plots and plots with gophers (G), by harvest. 58

Table 4a. Protein (%) of Wrangler (W) and Spredor 2 (S) alfalfa in control plots (C) and plots with gophers (G). 59

Table 4b. Protein (%) of Wrangler (W) and Spredor 2 (S) alfalfa in control plots (C) and plots with gophers (G), by harvest. 58

Table 5a. Relative feed value of Wrangler (W) and Spredor 2 (S) alfalfa in control plots (C) and plots with gophers (G). 60

Table 5b. Relative feed value of Wrangler (W) and Spredor 2 (S) alfalfa in control plots (C) and plots with gophers (G), by harvest. 60

Table 6. Elements (% or ppm) found in Wrangler (W) and Spredor 2 (S) alfalfa in control plots (C) and plots with gophers (G). 61

List of Appendices

App.		Page
A	Chemical analysis of soil found in Wrangler (W) and Spredor 2 (S) alfalfa control plots (C) and plots with gophers (G).	62
B	Elements (% or ppm) found in Wrangler (W) and Spredor 2 (S) alfalfa in control plots (C) and plots with gophers (G).	63

INTRODUCTION

In the early 1800s, North American buffalo (*Bos bison*) numbered around 40 million with similar numbers of pronghorn (*Antilocapra americana*) (Mielke 1977). As these large herbivores heavily grazed the prairies, they compacted the ground which accelerated forb growth. Pocket gophers (*Geomyidae*) thrived on the large roots of these forbs and worked the soil as they burrowed. This disturbance of the soil improved soil quality, provided a seedbed for invading annuals, and increased vegetative growth preferred by grazers. Thus, gophers played a role in maintaining the integrity of the prairie ecosystem (Mielke 1977). Prairie dogs (*Cynomys* spp.) had a similar role; their burrowing activity created areas of more succulent and nutritious grass. Krueger (1986) and Detling and Whicker (1987) showed that large grazers such as bison, pronghorn, and elk (*Cervus elaphus*) prefer to graze in prairie dog towns. Prairie dog towns also provide habitat for other species such as the black-footed ferret (*Mustela nigripes*), which nearly became extinct because of the decline in prairie dog populations (Miller et al. 1994).

Efforts to eradicate prairie dogs and other rodents became intense in the early 1900s. U.S. farmers and ranchers campaigned against what they felt was an onslaught of rodents such as pocket gophers, prairie dogs, and ground squirrels (*Sciuridae*) degrading their land. Annual losses of $300,000,000 to crops and forage land were attributed to rodent damage. Federal and state governments and private individuals spent large sums of money trying to exterminate the rodents. In one instance, over 4 tons of strychnine were used to destroy prairie dogs and ground squirrels on over 7,200,000 ha of farm and range lands (Bell 1921). These efforts led to a 98% decline in prairie dog numbers by 1960 (Miller et al. 1994).

Since those days, scientific studies have altered views about rodent species. Early 1900 estimates indicated that prairie dogs reduced range productivity 50 - 75%. However, there is really only a 0 - 7% level of competition between prairie dogs and livestock (Miller et al. 1994). The beneficial impact of rodents on the ecosystem, such as the pocket gopher's role in the prairie ecosystem, has become apparent.

The harmful effects of certain agricultural practices such as excessive fertilizer and pesticide use also have become apparent. The concept of LISA (low-input sustainable agriculture) has grown in response to the increasing awareness of these harmful practices. The goal of LISA is to develop environmentally sound agricultural methods while maintaining profitability (Anderson and Lockeretz 1992). It is expected that these methods will lower production costs while increasing farm profits (Bell 1987). Methods include erosion control, crop improvement, and reduced fertilizer and pesticide use (Bell 1987). Crop rotation conserves nutrients and reduces pesticide use (Case 1989). Cultural control, or planting crop varieties that do not support the pest population, avoids the use of poisons (Case and Jasch 1994).

My first goal was to evaluate the success of cultural control of plains pocket gopher (*Geomys bursarius*) damage to alfalfa (*Medicago sativa*). The legume alfalfa is an excellent crop to use in crop rotation because it restores soil nitrogen. However, pocket gophers frequently invade alfalfa fields and reduce yields 17 - 46% (Case 1989). These losses, and the money and time spent to control gophers, may deter farmers from using alfalfa in crop rotation. Control methods, such as poisoning, may do more harm than good. Poison baits may harm nontarget species and are ineffective in permanently controlling the gopher population (Hegdal and Gatz 1976, Sullivan and Hogue 1987). A cultural control may deter gophers without harming other species.

My second goal was to examine how gophers affect alfalfa forage quality. There is little information about belowground herbivory (especially by mammals) and forage quality. If gophers do not adversely affect forage quality, then it may not be cost effective to attempt to extirpate them.

I compared the impacts of the plains pocket gopher on 2 varieties of alfalfa. One variety is tap rooted while the other variety has a more fibrous root system. The alfalfa variety which exhibits the least reduction in yield and forage quality due to gophers may be a suitable cultural control method. This would reduce the use of lethal control methods and support the goals of LISA.

LITERATURE REVIEW

ALFALFA

Alfalfa is the most important forage crop in North America (Watkins et al. 1989). In recent years in Nebraska, about 580,000 ha of alfalfa have been produced annually (Moomaw and Martin 1990). Up to 100% of the protein needs of most livestock can be supplied by alfalfa. Alfalfa also provides large amounts of vitamins, minerals, and energy for livestock (Anderson and Nichols 1983). However, forage quality and mineral composition of alfalfa depend on genetic variations, soil and climate conditions, and management practices (Pathak and Jakhmola 1983).

Alfalfa benefits the soil as its root nodules convert nitrogen from the air into a form plants can use (Anderson and Nichols 1983). Annually, alfalfa fixes over 200 kg of nitrogen per hectare (Stubbendieck et al. 1979a.) When used in crop rotation, a 3 year old stand of alfalfa should supply the nitrogen needs of a 5020 kg/ha (80 bushel/acre) dryland corn (*Zea maize*) crop in the first year (Moomaw and Martin 1990). Alfalfa also benefits soil by adding organic matter, increasing water filtration, improving soil structure, and providing erosion control (Anderson and Nichols 1983).

Different alfalfa varieties are developed to emphasize desirable features. Spredor 2 is a creeping rooted alfalfa developed by Northrup King Co., MN to be winterhardy and self-rejuvenating. The creeping root system consists of a main tap root with many lateral roots that can send up new shoots. However, Spredor 2 has relatively low yields compared to other varieties (Northrup King Co. 1982). Wrangler, which was developed by the USDA-ARS and the Nebraska and Minnesota Agricultural Experiment Stations for pest resistance and winterhardiness, has a single tap root (Kehr et al. 1986). Spredor 2's yield was only 73% that of Wrangler's by the fourth year post-planting (Hardman 1988). The reason for this may be that more of Spredor 2's energy goes into its fibrous root system than aboveground vegetation, while more of Wrangler's energy goes into aboveground vegetation than its single tap root.

POCKET GOPHERS

Pocket gophers are fossorial rodents found in the western hemisphere from Panama to Alberta. Of the 33 species of gophers, 6 occur in the Great Plains. The plains pocket gopher ranges from southern Manitoba south to Texas, in the east from western Wisconsin south to western Louisiana, and in the west from eastern Wyoming south through Texas (Case and Jasch 1994). The subspecies *G. b. majusculus* is the only gopher in eastern Nebraska (Case and Sargeant 1982). Plains pocket gophers weigh 300 - 450 g (Nowak and Paradiso 1983) and are 18 - 36 cm long (Case and Jasch 1994).

Gophers spend the majority of their time underground. Their bodies are adapted to this fossorial lifestyle. Most notable are the large incisors and foreclaws with which the gophers dig. Their heads are large in proportion to their bodies because of thick and rigid skull bones and large muscle masses. The broad shoulders and forearms also are heavily muscled. Gophers have small eyes and ears. Pocket gophers derive their name from the external fur-lined cheek pouches in which they carry food (Grinnell 1923).

Gophers eat vegetative material including forbs, grasses, shrubs, and trees. They feed in three ways: eating roots they encounter while digging, pulling vegetation into their tunnels, and occasionally feeding at the surface on vegetation near their holes (Case and Jasch 1994). The plains pocket gopher prefers grasses while the northern pocket gopher (*Thomomys talpoides*) prefers forbs (Myers and Vaughan 1964). Preferred plant parts change with the seasons. During late fall and winter, roots are preferred. In the spring, leaves and stems become more important (Luce et al. 1980). Gophers store food in underground chambers. They derive water from their food (Nowak and Paradiso 1983).

Gophers dig most actively in the spring and fall (Stubbendieck et al. 1979b). When a gopher digs, it loosens soil with its incisors and claws and pushes the soil beneath and behind it. The lips close behind the incisors to keep dirt out of the mouth. When enough soil has accumulated, it then turns around and with its forefeet and chest pushes the soil to the surface, creating a fan-shaped mound of soil. It then plugs the hole leading to the surface (Grinnell 1923). The mounds are 30 - 46 cm wide and 10 - 15 cm high. As they extend their burrow systems, more mounds appear on the surface (Stubbendieck et al. 1979b).

A gopher (*Thomomys*) digs 1 to 3 mounds a day and may dig up to 70 per month. This results in the movement of about 2 metric tons of soil per year. The main burrow lies 10 - 46 cm below the surface and the tunnel diameter is about 7 cm, depending on the size of the gopher. Lateral branches lead to the surface while deeper branches lead to nests and food caches. The burrow system may consist of 180 m of tunnels. The home range of a gopher can be up to 560 m^2 (Case and Jasch 1994). A burrow system can underlie up to 7.5% of a field and mounds can occupy 5 - 25% of a field (Reichman 1988). Plains pocket gopher populations may reach up to 20/ha (Case and Jasch 1994).

As with most fossorial animals, gophers are solitary and very aggressive to conspecifics except during the breeding season (Bandoli 1987). During this time, males extend their tunnels or travel above ground in search of females' burrows. Plains pocket gophers mate from March to May. In the northern parts of the range, a female has one litter of 1 to 8 young per year. In the southern parts of the range, a female may have more than 1 litter of 1 to 3 young per year (Nowak and Paradiso 1983). Young leave their mother in June or July by dispersing above ground (Stubbendieck et al. 1979). A gopher may live 5 years or more (Nowak and Paradiso 1983).

HERBIVORY

A plant's responses to the stresses caused by herbivory are affected by nutrition, water, photosynthesis, hormonal balance, and genetic controls (Dyer et al. 1993). There are 3 views on how herbivory affects plant fitness. The first is that herbivory is detrimental to the plant. The second is that the plant will exhibit compensatory growth for low levels of herbivory. The third is that the plant overcompensates for moderate levels of herbivory (McNaughton 1983). The extent that herbivory benefits plants is debated. From her examination of the literature, Belsky (1986) concluded that there is no convincing evidence that herbivory benefits plants. However, from their review of the literature, Dyer et al. (1993) stated that at low levels, herbivory increases plant productivity, while at extreme levels, herbivory reduces plant productivity.

Herbivory affects other factors in addition to plant productivity. Herbivores selectively consume species. Also, plant species vary in their tolerances to herbivory (Archer and Smeins 1991). As herbivores graze, more light becomes available for remaining plants (Inouye et al. 1987). These factors cause a shift in competition among the plants that alters species composition and diversity (Archer and Smeins 1991). Grazing also creates a greater ratio of root-to-remaining-aboveground biomass, which improves the plant's water relations (Svejcar and Christiansen 1987). This may be an advantage in arid and semiarid lands (Archer and Smeins 1991).

Nutritive value, or forage quality, refers to the nutritional attributes of a forage in relation to its overall value to the consuming animal. Forage quality considers protein, fiber, and elements (Huston and Pinchak 1991). High protein and low fiber are the most desired (Anderson and Mader 1994). Because a plant's chemical composition is the result of the interaction of growth and nutrient supply (Martin and Matocha 1973), herbivory may influence forage quality. Defoliation reduces root initiation and extension and increases root mortality. This affects the belowground nutrient exchange pool (Archer and Smeins 1991). However, urine and feces of the herbivores increase soil nutrients (Georgiadis and McNaughton 1990). Also, grazing maintains plants in a physiologically younger state of growth in which protein is higher and fiber is lower than in mature plants (Church 1979).

Georgiadis and McNaughton (1990) studied livestock grazing on savanna grasses in Kenya and found that forage quality was higher in vegetation from areas of high herbivore use intensity than low. This difference in forage quality was attributable to how the livestock affected soil nutrients and plant species composition. By increasing available soil nutrients, livestock improved forage fiber and elemental quality of the vegetation. As herbivore use intensity increased, grazing-tolerant species replaced grazing-intolerant species, which altered elements available to the livestock.

More research has been devoted to aboveground herbivory than belowground herbivory (Andersen 1987). However, for several reasons, belowground herbivory may be more extensive than aboveground herbivory. First, there may be a greater biomass of subterranean animals than those that dwell above ground. All major phyla except Coelenterata and Echinodermata are represented in the world's soils (Hole 1981). The three most common phyla found below the soil's surface are Nemotoda, Arthropoda, and Chordata. Second, belowground herbivory occurs at some level in all communities of terrestrial vascular plants. Greater than 50% of net primary productivity is allocated to belowground plant parts. For some species this may be 90% (Andersen 1987).

Root pruning experiments demonstrate that following pruning, net photosynthesis rate initially decreases and total biomass and number of aboveground shoots decrease. However, root pruning also stimulates new root growth, which compensates for the root loss. Natural belowground herbivory is more involved than laboratory experiments. A plant's response to belowground herbivory depends on many factors including the feeding mode and size of the animal, the plant's ability to do without or substitute for the function lost to herbivory, and the time of year in which herbivory occurs (Andersen 1987). Belowground herbivory by insects reduces vegetation yields, the rate of nutrient and water uptake, and the carbohydrate supply. These losses in turn depress plant reproduction (Brown and Gange 1991). Nematodes cause a 10% reduction in crop yields worldwide and decrease crop quality (Lamberti et al. 1994). In the U.S., nematodes cause 3% reduction in alfalfa yields and $500 million in crop damage annually (Decker 1981). From their review of the literature, Brown and Gange (1991) concluded that belowground herbivory is at least as important as aboveground herbivory.

BENEFITS OF GOPHERS

Though traditionally viewed as a pest species, gophers benefit soil and vegetation in many ways. As gophers loosen soil, it becomes more porous and holds more water and oxygen. This facilitates roots in respiring, absorbing mineral ions, and penetrating the soil (Mielke 1977). Gophers increase the organic content of the soil by not eating all the food they cache and defecating underground (Grinnell 1923). This influences soil structure, nutrient availability, and microorganism activity (Mielke 1977). As organic matter decomposes, chemical elements, especially carbon, nitrogen, phosphorous, and potassium, are rapidly liberated and become available to the plant (Ritter 1992). Gophers bring this soil to the surface where it is weathered and added to the topsoil (Grinnell 1923). These benefits also result from the burrowing activities of other animals such as protozoa, worms (*Oligochaeta*), insects (*Insecta*), prairie dogs, kangaroo rats (*Dipodomys* spp.), and ground squirrels (Koford 1958).

Gopher activity may counteract the impact of large grazing herbivores on soil. As large animals graze, they pack the soil which makes it less suitable for plant growth (Grinnell 1923, Hall 1955). Eventually, forbs with large roots replace the grasses. These forbs are less desirable to the grazers, but because of the larger roots, they are preferred by gophers. As gophers feed on these forbs, they loosen the soil which hastens the return of the grass. Though dense gopher populations are associated with overgrazing and forbs, it is the overgrazing and not the gophers which causes the problem (Hall 1955).

DAMAGE BY GOPHERS

The gopher's digging and feeding behaviors seem to have earned it a bad reputation among many farmers and ranchers. Digging destroys underground utility cables and irrigation pipes, tunnels cause water to runoff, and mounds dull farming equipment and erode the soil (Case and Jasch 1994). Vegetation also is affected. As gophers dig, they consume and cut roots. Air spaces may desiccate roots. Mounds cover vegetation and provide germination sites for weeds (Reichman and Smith 1985). Martinsen et al. (1990) found a greater than expected proportion of herbaceous perennial dicots on mounds of the valley pocket gopher (*Thomomys bottae*) than on non-mounded areas. Reichman and Smith (1985) found a 33% reduction of plant biomass directly over burrows as compared to control sites. On sands and silty range sites in western Nebraska, gophers reduced forage production 18 - 49% (Foster and Stubbendieck 1980). On dryland alfalfa in eastern Nebraska, gophers reduced alfalfa yields 37 - 46% and reduced alfalfa densities 28 - 32% (Luce et al. 1981).

CONTROL OF GOPHERS

Common gopher control methods are rodenticides, traps, and fumigants. Federally registered rodenticides recommended for pocket gophers include strychnine alkaloid (0.25 - 0.5% active ingredients) and zinc phosphide (2%) on grain baits. Other registered rodenticides include the anticoagulants diphacinone and chlorophacinone. The bait should be placed in the tunnel system by hand or mechanically with a burrow builder. The recommended rate of applying strychnine alkaloid with a burrow builder is 1.1 - 2.2 kg/ha (Case and Jasch 1994).

Tunberg et al. (1984) studied the effect of baiting to control *Thomomys* spp. which feed on conifer seedlings in the far western states. Baiting was ineffective because it provided only temporary control and had to be repeated for several years until the trees were large enough to withstand gopher damage. Also, areas became rapidly repopulated as survivors reproduced and gophers from adjacent areas invaded unoccupied burrows. Tunberg et al. (1984) suggested using long lasting baits, such as those imbedded in paraffin, to control invading gophers. In addition, baiting becomes inefficient if the gophers ingest sublethal doses and become bait shy (Bonar 1995).

Baiting could harm non-target species such as badgers (*Taxidea taxus*) and coyotes (*Canis latrans*) which prey on gophers. Spilled grain bait and bait exposed in collapsed artificial tunnels may poison seed eating birds (Hegdal and Gatz 1976). Raptors may be poisoned by consuming gophers that either came to the surface with a cheek pouch full of bait (Hegdal and Gatz 1976) or died at the surface (Case and Jasch 1994).

Because baiting may harm other wildlife and rodent populations recover relatively rapidly from losses in numbers (Hegdal and Gatz 1976, Sullivan and Hogue 1987), controlling habitat may be a more effective method of regulating gopher damage. Sullivan and Hogue (1987) suggested using herbicides to control northern pocket gophers. They found that intensive herbicide culture in apple orchards significantly reduced vole (*Microtus* spp.) and northern pocket gopher populations and damage due to removal of food and cover.

Cultural control is another means of manipulating habitat. It may involve rotating a vulnerable crop, such as alfalfa, with crops such as grains that do not support gopher populations. Another cultural strategy would be planting the nonvulnerable crop around the vulnerable crop. Also, crop varieties differ in their vulnerability to gophers (Case and Jasch 1994). For example, gophers prefer tap rooted plants over rhizomatous plants (Mielke 1977) and rhizomatous plants may have better recovery from damage (Case 1989). So, in gopher-populated fields, a fibrous rooted alfalfa variety may have an advantage over a tap-rooted variety. An additional benefit of cultural control is that the natural herbivore-vegetation interactions continue. The gophers continue loosening and mixing soil and adding nutrients to it which in turn benefits the vegetation.

Management decisions must not be based solely on the negative values associated with a species. One must consider the species' interactions with the soil, vegetation, and other animals (Sieg 1987). When dealing with pocket gophers, one must decide if the benefits of a control method outweigh the costs and whether the benefits will be long lasting. Directly reducing gopher numbers such as by poisoning provides only short-term relief since rodent populations recover rapidly. Manipulating habitat, such as through cultural methods, provides longer-term control, does not introduce toxins to the environment, and permits natural interactions to continue.

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CHAPTER 1

THE EFFECTS OF PLAINS POCKET GOPHERS (*GEOMYS BURSARIUS*) ON ALFALFA (*MEDICAGO SATIVA*) AND WEED BIOMASS

THE EFFECTS OF PLAINS POCKET GOPHERS (*GEOMYS BURSARIUS*) ON ALFALFA (*MEDICAGO SATIVA*) AND WEED BIOMASS

ABSTRACT

Pocket gopher feeding and burrowing behaviors reduce alfalfa yields, thus prompting the use of toxicants to control gophers. A cultural control of gopher damage might reduce the use of toxicants. I determined the effects of plains pocket gophers on yield, root biomass, density, and weed biomass of Wrangler and Spredor 2 alfalfa. The tap-rooted Wrangler produces higher yields than the creeping-rooted Spredor 2. However, I predicted that Spredor 2's ability to send up new shoots when roots are damaged may compensate for gopher damage. The presence of gophers reduced yields of Wrangler 19% ($p = 0.01$), but not Spredor 2 ($p = 0.30$). Root biomass was not affected by the presence of gophers ($p \geq 0.46$). Spredor 2 density decreased 15% when gophers were present for less than 1 year ($p = 0.09$) and 11% when gophers were present for 1 to 2 years ($p = 0.04$), while Wrangler density decreased 10% when gophers were present for 1 to 2 years ($p = 0.05$). Weed biomass increased 390% ($p = 0.03$) and 256% ($p = 0.08$) in Wrangler and Spredor 2, respectively, when gophers were present for 1 to 2 years. As measured by yields, Spredor 2 appeared to withstand gopher damage better than Wrangler.

INTRODUCTION

Pocket gophers (Geomyidae) frequently invade alfalfa (*Medicago sativa*) fields, reducing yields 17 - 46% (Case 1989). As gophers dig underground burrow systems, they cut and consume roots, reducing biomass by over one-third (Reichman and Smith 1985). They also consume aboveground vegetation by pulling it down into their tunnels or by feeding at the surface near their holes (Case and Jasch 1994). Soil mounds cover vegetation and provide germination sites for weeds (Reichman and Smith 1985, Martinsen et al. 1990).

However, gopher burrowing and feeding behaviors benefit soil and vegetation. Gophers bring soil to the surface where it is weathered and added to the topsoil (Grinnell 1923). As gophers loosen soil, it becomes more porous and holds more water and oxygen. This facilitates roots in respiring, absorbing mineral ions, and penetrating the soil (Mielke 1977). Gophers increase the organic content of the soil by not eating all the food they cache and by defecating underground (Grinnell 1923). This enhances soil structure, nutrient availability, and microorganism activity (Mielke 1977). As organic matter decomposes, chemical elements, especially carbon, nitrogen, phosphorous, and potassium, are rapidly liberated and become available to the plant (Ritter 1992).

Toxicants, trapping, and fumigating offer only temporary control of gophers because rodent populations recover relatively rapidly (Sullivan and Hogue 1987). Toxicants also could harm non-target species (Hegdal and Gatz 1976). Altering habitat may be more cost effective and lessen the risk to other wildlife.

One way to manipulate the gopher's habitat is through cultural control: selectively planting crops that do not support gopher populations (Case and Jasch 1994). Gophers prefer tap-rooted plants over fibrous-rooted plants (Mielke 1977) and fibrous-rooted plants may have better recovery from damage (Case 1989). So, in gopher-populated fields, a fibrous-rooted alfalfa variety may have an advantage over a tap-rooted variety.

My objective was to evaluate the success of cultural control of plains pocket gopher (*Geomys bursarius*) damage to 2 varieties of alfalfa. I measured the impacts of gophers on yield, root biomass, plant density, and weed biomass. Hardman (1988) reported that on average, the tap-rooted Wrangler yielded 27% more than the creeping-rooted Spredor 2 by the third and fourth years post-planting. However, Spredor 2 can send up new shoots when roots are damaged (Northrup King Co. 1992). I wanted to test whether the feeding and burrowing activities of pocket gophers stimulated shoot production in Spredor 2 which may compensate for the adverse effects of pocket gophers.

Predictions

On plots without gophers, I predicted that Wrangler would have higher yields, but lower root biomass than Spredor 2, and that Spredor 2 and Wrangler would have the same plant densities since they were planted at the same rate. I predicted that alfalfa yields, root biomass, and densities would be higher on plots without gophers than plots with gophers, but that Spredor 2, because it sends up new shoots, would suffer less damage due to gophers than Wrangler. Thus, Spredor 2 would have less of a decrease in yield, root biomass, and density than Wrangler on plots with gophers versus plots without gophers.

Even though Spredor 2's more extensive root system may be able to compete better with weeds than Wrangler's root system, Spredor 2 has lower yields which may allow more light for weed growth. Therefore, I predicted that weed biomass would be the same in Wrangler and Spredor 2 plots. However, weed biomass on plots with gophers would be higher than plots without gophers because mounds provide germination sites for weeds. Furthermore, on plots with gophers, weed biomass would increase less on Spredor 2 than Wrangler due to Spredor 2's creeping root system, ability to rejuvenate itself, and smallersized gopher mounds (Jasch 1992).

STUDY AREA

The study area was located at the University of Nebraska Agricultural Research and Development Center, Section 6, Township 6 North, Range 8 East, Saunders County, east-central Nebraska. The area is characterized by flat to gently rolling terrain with temperate climate and moderate precipitation. Soils are primarily Filmore and Sharpsburg silty clay loams with 0 to 2% slope (Elder et al. 1965).

METHODS

I live-trapped plains pocket gophers from farms in Lancaster County. The trap, designed by Baker and Williams (1972) and modified by Jasch (1992), consisted of a 40 cm PVC pipe 9 cm in diameter. It was baited with carrots. Captured gophers were brought back to the lab, weighed, sexed, and tattooed for future identification. Because they are aggressive, each gopher was first anesthetized with 0.01 cc ketamine hydrochloride (Ketaset, 100 mg/ml) and 0.03 cc xylazine (Rompun, 20 mg/ml), as recommended by Jasch (1992). Tattooing involved injecting black India ink under the skin of toes (Bandoli 1987). Gophers were kept overnight to ensure recovery from anesthetization.

I released the gophers onto the gopher plots. To encourage it to dig, I placed each gopher in a 10 cm deep hole dug with a 1.2 l auger bucket 8 cm in diameter. To prevent the gophers from leaving and to protect them from predators, I encircled each gopher's hole with chicken wire for 1 to 2 weeks. Gopher activity was then monitored by the appearance of mounds. In each gopher plot, vegetation sampling was restricted to the area circumscribed by mounds. Mound numbers averaged 15 in each plot.

Alfalfa was harvested 4 times in 1995 and 3 in 1996. At an early bloom stage prior to each harvest, I sampled alfalfa for aboveground biomass. Five sites in each plot were randomly chosen. At each site, a 1.0 x 0.5 m^2 sampling frame was placed with the long axis oriented north-south (perpendicular to the rows). Rechargeable grass clippers were used to clip all vegetation rooted within this frame to a height of 2.5 cm. The frame was flipped once to the north and clipping was repeated to obtain a 1.0 m^2 sample. Weeds were separated from the alfalfa. Each of the 5 vegetation samples from each plot were placed in separate labeled paper bags and returned to the lab (Luce et al. 1981).

At the lab, I weighed each vegetation sample. I took a grab sample (about 100 g) from each bag, weighed it, and dried it in a convection oven at 70 C until a constant weight was obtained. The dry weight of the original larger sample was calculated from the dry weight of the grab sample. Dry weights of the 5 samples of each plot were then averaged to estimate both alfalfa and weed biomass (g/m^2) for each plot. Biomass was then converted to kg/ha.

Prior to the third harvest each year, I collected root samples with a 1.2 l auger bucket, 8 cm in diameter and 21.5 cm deep, at 5 random sites within each plot. At the lab, I separated roots from the soil using 2-mm^2 mesh sieves, washed the roots, and pooled the 5 samples of each plot. Roots were frozen at 0 C until they were dried in a convection oven at 70 C to obtain dry mass (g/l) for each plot (Bohm 1979).

After the fourth harvest in 1995 and after the third harvest in 1996, I determined alfalfa density by counting the number of plants rooted within a 0.5 x 0.5 m^2 frame at 5 random sites within each plot.

The study design was a split plot with the main units (alfalfa varieties) in a randomized complete block design. The site consisted of 9 paired fields (blocks) planted with alfalfa in August 1992. Half of each pair was planted with Spredor 2 and half with

Wrangler. Each field of Spredor 2 and Wrangler was further divided in half and each half (referred to as a plot) (0.25 - 0.35 ha) was randomly assigned as gopher, which was stocked with gophers, and control, which was not stocked with gophers (Figure 1).

I used analysis of variance to detect significant differences in the data (SAS Institute Inc.). I considered only the first 3 harvests of each year. Unless year affected results, I combined 1995 and 1996 results to increase power. If results were affected by how long (less than 1 year or 1 to 2 years) gophers had inhabited the plots, I analyzed the less-than-1-year plots separately from the 1-to-2-year plots.

RESULTS AND DISCUSSION

Gophers

I trapped 52 gophers over 3 summers. Five died in captivity from the following causes: 1 prolapsed uterus, 1 broken back, and 3 unknown. Three died in the traps: 1 from heat, 1 from exposure to the sun after the trap was dug up by a badger (*Taxidea taxus*), and 1 drowned. I kept a record of my efforts to trap 45 of the gophers. Evidence that a gopher visited a trap was indicated by a trapped gopher or the trap was either set off or plugged with soil. Also, gophers may have plugged the tunnel leading to the trap, but I did not record these instances until the third summer. Thus, there were a minimum of 173 visits by gophers. Trapped gophers accounted for 26% of the 173 known visits.

I released 44 gophers onto the study site, but only 8 persisted. Prior to the first harvest in 1995, 4 gophers were successfully stocked on 2 blocks. Thus, through 1995, gophers were present for less than 1 year. Prior to the first harvest in 1996, another 4 gophers were successfully stocked on an additional 2 blocks. Thus, through 1996, 4 gophers were present for less than 1 year and 4 gophers were present for 1 to 2 years. The other gophers either left the area or were killed by predators. Badger activity and possibly weasel (*Mustela* spp.) activity was seen on the study sites.

Alfalfa Yields

Average yield of alfalfa in the United States is 6750 kg/ha (Undersander et al. 1991). Wrangler control yields were above this average (7290 - 8050 kg/ha), but Spredor control yields were less (6690 - 6970 kg/ha) (Tables 1a and 1b). On control plots, Wrangler had 16% higher yields than Spredor 2 in 1995 and 2% higher yields in 1996 ($p = 0.02$) (Table 1a). These differences are not as great as the 27% higher average yields for Wrangler for the third and fourth years post-planting reported by Hardman (1988). Wrangler yields decreased 17% ($p = 0.003$) from 1995 to 1996, but year did not affect Spredor 2 ($p = 0.31$). May and June of 1996 had 83% more rain than May and June of 1995 (Natl. Oceanic and Atmos. Adm. 1995, 1996), resulting in standing water in the fields for much of this time. Alfalfa is susceptible to damage under permanently wet conditions, which cause poor aeration and increase disease (Anderson and Nichols 1983, Hay 1990). Perhaps Spredor 2's root system was better able to cope with the wet conditions and its rejuvenating ability helped it to recover better than Wrangler from the wet conditions.

Though significant variety differences were found in control plots when all 9 blocks were analyzed, none ($p = 0.20$) were detected when just the 4 blocks with gophers were analyzed. This may indicate that if differences were not found in the analysis of blocks with gophers, it may be due to the low number of blocks (at $\alpha = 0.10$, power to detect variety differences = 0.14, power to detect treatment differences = 0.42).

I predicted that gopher activity would cause a greater decrease in Wrangler yields than in Spredor 2 yields due to the differing root systems. Gophers reduced Wrangler yield 19% ($p = 0.01$), but did not affect the yield of Spredor 2 ($p = 0.30$) (Table 1b). While Wrangler may have greater aboveground yields than Spredor 2, its single taproot cannot produce new plants as can Spredor 2's creeping root system. Thus, Spredor 2 may be able to compensate for gopher damage. Also, Jasch (1992) demonstrated that gophers produce smaller mounds in Spredor 2.

Alfalfa Root Biomass

Root biomass did not differ between varieties ($p \geq 0.30$) or treatments ($p \geq 0.46$) (Table 2). This indicated that, contrary to what I predicted, gophers did not affect root biomass. However, the root biomass results may be influenced by the sampling method. First, there were only 4 blocks with established gophers. Second, only 5 1.2 l samples were taken from each sampling site. Each individual sample contained a very low biomass of roots, on average no more than 10 g of roots. The combination of these 2 factors may mean that sample size was too low to detect differences.

Nevertheless, biomass is not a good indicator of root function. Root depth, the number of deep roots versus the number of lateral spreading roots, the number of root hairs, and the numbers of branching, secondary, and tertiary roots are better indicators (Vose 1990). Because it can exploit more soil volume, a branched root system is more effective in absorbing nutrients than an unbranched system (Caradus 1990, Vose 1990). Perhaps if I had focused on these factors rather than biomass, I would have been able to determine if gophers had different effects on the roots of the two varieties.

Alfalfa Density

As predicted, on control plots, Wrangler and Spredor 2 did not differ from each other in density ($p \geq 0.24$) (Tables 3a and 3b). Alfalfa density was affected by how many years the gophers inhabited the plots ($p \leq 0.01$). When gophers were present for less than 1 year, Spredor 2 density decreased 15% ($p = 0.09$). When gophers were present for 1 to 2 years, Spredor 2 density decreased 11% ($p = 0.04$) and Wrangler density decreased 10% ($p = 0.05$). The reduction in Spredor 2 density appears to indicate that gopher activity did not stimulate shoot production.

However, Luce et al. (1980) reported that the percentage of leaves and stems in the diets of plains pocket gophers increased from 10% during the winter to 50% - 60% in the summer. If gophers consumed aboveground vegetation during my study, they would have to consume more individual plants of Spredor 2 than Wrangler to get the same amount of biomass since Spredor 2 generally had lower yields than Wrangler. Perhaps this negated any increase in density by Spredor 2.

Weed Biomass

Competition with weeds may influence alfalfa yields, root biomass, and densities. Spredor 2's extensive root system may be able to compete better with weeds than Wrangler's tap root, thus giving Spredor 2 the advantage. But Spredor 2's lower yields may be a disadvantage by allowing more light in for weed growth. As predicted, there were no differences in weed biomass between the varieties on control plots ($p \geq 0.82$) in either the analysis of all 9 study site blocks or just the 4 blocks containing gophers (Tables 4a, 4b, and 4c).

Weed biomass was affected by how many years the gophers inhabited the plots ($p \leq 0.006$). When gophers were present for less than 1 year, they did not affect weed biomass ($p \geq 0.19$) (Table 4b). When gophers were present for 1 to 2 years, they increased weeds 390% on Wrangler ($p = 0.03$) and 256% on Spredor 2 ($p = 0.08$) (Table

4c). Perhaps the longer gophers are in an area, the more mounds they create which provide more germination sites for weeds. Of more significance, perhaps weed seeds remained on mounds from the previous year. Thus, weeds became established sooner on older mounds than on newer mounds. Martinsen et al. (1990) reported that herbaceous perennial dicots become established and maintained on pocket gopher disturbances. They found that areas with mounds less than 1-year-old were not yet colonized by dicots, but areas with mounds 1- to 2-years-old were colonized by many species of dicots. Jasch (1992) showed that mound diameter was larger in Wrangler than in Spredor 2, providing a larger area for weed germination in Wrangler. Though Wrangler had 58% more weeds than Spredor 2, this difference was not significant ($p = 0.17$).

CONCLUSION

The purpose of this study was to determine if Spredor 2 could serve as a cultural control of gopher damage. Because Spredor 2 can send up new shoots from its creeping root system, I expected Spredor 2 to have an advantage over Wrangler in gopher inhabited fields. Gophers reduced Wrangler yields and not Spredor 2 yields, but unexpectedly decreased Spredor 2 density. Perhaps gopher activity did not stimulate shoot production by Spredor 2, or gophers fed on stems of Spredor 2. Also, larger gopher mounds in Wrangler may have contributed to the yield loss of Wrangler. Though Spredor 2 did not suffer yield loss to gopher damage, one cannot ignore the increase in weeds in both Spredor 2 and Wrangler, or the low number of blocks on which gophers were established. In the next chapter, I will evaluate the impact of gophers on forage quality of Wrangler and Spredor 2.

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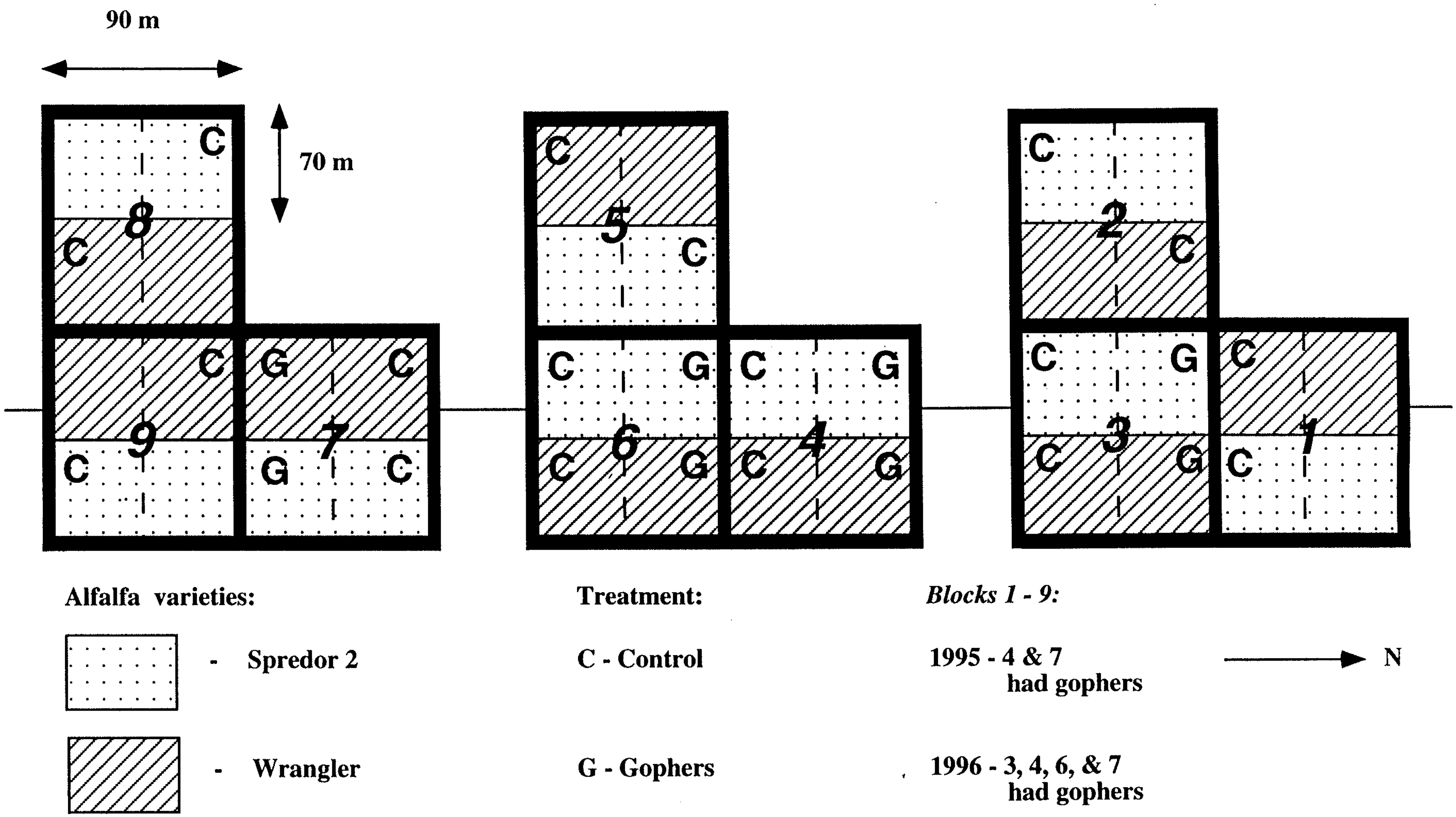

Fig. 1. Study site at the University of Nebraska Agricultural Research and Development Center, Saunders County, Nebraska.

Table 1a. Yields (kg/ha) of Wrangler (W) and Spredor 2 (S) alfalfa on 9 blocks without gophers in 1995 and 1996.

	1995		1996		
Comparison	$\bar{x}$	SE	$\bar{x}$	SE	p
Wrangler	8050	434	6715	245	0.003
Spredor 2	6969	271	6566	193	0.31
W*S					0.02
1995*1996					0.02

Table 1b. Yields (kg/ha) of Wrangler (W) and Spredor 2 (S) alfalfa on 4 blocks of control plots (C) and plots with gophers (G) in 1995 and 1996.

	Control		Gophers		
Comparison	$\bar{x}$	SE	$\bar{x}$	SE	p
Wrangler	7290	669	5940	711	0.01
Spredor 2	6690	679	6240	792	0.30
WC*SC					0.20
WG*SG					0.60

Table 2. Root biomass (g/l) of Wrangler (W) and Spredor 2 (S) alfalfa in control plots (C) and plots with gophers (G) in 1995 and 1996.

	Control		Gophers		
Comparison	$\bar{x}$	SE	$\bar{x}$	SE	p
Wrangler	1.02	0.21	0.63	0.22	0.46
Spredor 2	1.42	0.35	1.29	0.51	0.80
WC*SC					0.44
WG*SG					0.30

Table 3a. Alfalfa density/m^2 of Wrangler (W) and Spredor 2 (S) in control plots (C) and plots inhabited by gophers (G) for less than 1 year in 1995 and 1996.

	Control		Gophers		
Comparison	$\bar{x}$	SE	$\bar{x}$	SE	p
Wrangler	31.80	8.86	31.80	7.36	1.00
Spredor 2	30.20	3.77	25.80	2.80	0.09
WC*SC					0.81
WG*SG					0.39

Table 3b. Alfalfa density/m^2 of Wrangler (W) and Spredor 2 (S) in control plots (C) and plots inhabited by gophers (G) for 1 to 2 years in 1996.

	Control		Gophers		
Comparison	$\bar{x}$	SE	$\bar{x}$	SE	p
Wrangler	26.80	2.00	24.00	2.40	0.05
Spredor 2	29.20	0.40	26.00	1.20	0.04
WC*SC					0.24
WG*SG					0.31

Table 4a. Weed biomass (kg/ha) in Wrangler (W) and Spredor 2 (S) alfalfa on 9 blocks without gophers in 1995 and 1996.

	1995		1996		
Comparison	$\bar{x}$	SE	$\bar{x}$	SE	p
Wrangler	87	33	329	105	0.004
Spredor 2	123	29	287	58	0.04
W*S					0.95
1995*1996					0.004

Table 4b. Weed biomass (kg/ha) in Wrangler (W) and Spredor 2 (S) alfalfa in control plots (C) and plots inhabited by gophers (G) for less than 1 year in 1995 and 1996.

	Control		Gophers		
Comparison	$\bar{x}$	SE	$\bar{x}$	SE	p
Wrangler	196	130	291	124	0.21
Spredor 2	219	109	318	116	0.19
WC*SC					0.82
WG*SG					0.79

Table 4c. Weed biomass (kg/ha) in Wrangler (W) and Spredor 2 (S) alfalfa in control plots (C) and plots inhabited by gophers (G) for 1 to 2 years in 1996.

	Control		Gophers		
Comparison	$\bar{x}$	SE	$\bar{x}$	SE	p
Wrangler	230	173	1128	481	0.03
Spredor 2	200	125	712	386	0.08
WC*SC					0.89
WG*SG					0.17

CHAPTER 2

THE EFFECTS OF PLAINS POCKET GOPHERS (*GEOMYS BURSARIUS*) ON ALFALFA (*MEDICAGO SATIVA*) FORAGE QUALITY

THE EFFECTS OF PLAINS POCKET GOPHERS (*GEOMYS BURSARIUS*) ON ALFALFA (*MEDICAGO SATIVA*) FORAGE QUALITY

ABSTRACT

Pocket gophers reduce alfalfa yields, but impacts of their feeding and burrowing behaviors on forage quality are not well documented. Forage quality and mineral composition of a plant depend on genetics, availability of nutrients in the soil, and the ability of the plant to absorb nutrients. I determined the effects of pocket gophers on the forage quality of 2 varieties of alfalfa, Wrangler and Spredor 2. Soil minerals did not differ between varieties or treatments ($p \geq 0.15$). The presence of gophers did not affect acid detergent fiber, neutral detergent fiber, relative feed value, protein, Al, Fe, P, S, or Si ($p \geq 0.12$). In Spredor 2, Cl increased 31% ($p = 0.05$) and Cu, Mn, and Zn decreased 15% ($p = 0.09$), 16% ($p = 0.08$), and 13% ($p = 0.0004$), respectively, on plots with gophers. In Wrangler, Cu, Mg, Mn, and Zn decreased 19% ($p = 0.05$), 14% ($p = 0.03$), 19% ($p = 0.04$), and 13% ($p = 0.002$), respectively, on plots with gophers. Where gophers were present for 1 to 2 years, Ca increased 7% ($p = 0.01$) in Spredor 2, but decreased 15% ($p = 0.002$) in Wrangler. Although the presence of gophers adversely affected more minerals in Wrangler than Spredor 2, all variables were within acceptable ranges for alfalfa. The variables that I used to check forage quality indicated that there were no substantial differences between varieties or due to belowground herbivory by pocket gophers.

INTRODUCTION

Alfalfa is the most important forage crop in North America (Watkins et al. 1989). Up to 100% of the protein needs of most livestock can be supplied by alfalfa. Alfalfa also provides large amounts of vitamins, minerals, and energy (Anderson and Nichols 1983). Forage quality measures the nutritional value of feed to the consuming animal. Forage quality considers acid detergent fiber (ADF), neutral detergent fiber (NDF), crude protein, relative feed value (RFV), and nutrients (Huston and Pinchak 1991). ADF, NDF, and crude protein are reported as a percentage of the dry matter of the feed. ADF measures cellulose, lignin, silica, insoluble crude protein, and ash, which are poorly digested by animals. NDF measures the amount of cell wall in the forage plant, which gives bulk to the feed, thus limiting how much an animal can consume. ADF and NDF determine RFV which measures the potential digestible energy intake of a forage. Crude protein measures true protein and nonprotein nitrogen. Animal feeds also must contain adequate minerals which are measured as parts per million or percent of the dry matter of the feed (Anderson and Mader 1994).

Forage quality depends on genetic variations, soil and climate conditions, and management practices (Pathak and Jakhmola 1983). The availability of nutrients in the soil influences forage quality (Corey and Schulte 1973). Soil pH, soil moisture, and soil organic matter affect the plant's ability to absorb nutrients. Levels of Mg in vegetation increase with increasing soil pH. High soil organic matter causes higher protein and lower fiber in vegetation (Pathak and Jakhmola 1983). Disease and insects also affect forage quality primarily by reducing the leaf/stem ratio. Leaves are higher in protein, while stems are higher in fiber. Thus, as the leaf/stem ratio decreases, protein decreases and fiber increases (Marten et al. 1988).

Grazing by herbivores maintains plants in a physiologically younger stage of growth in which protein is higher and fiber is lower than in mature plants (Church 1979). The urine and feces of herbivores increase soil nutrients (Georgiadis and McNaughton 1990). These processes improve forage quality. However, defoliation reduces root initiation, reduces root extension, and increases root mortality, thus decreasing mineral absorption by the plant (Martin and Matocha 1973). Though many studies have examined how aboveground herbivory affects plants (McNaughton 1983, Archer and Smeins 1991, Dyer et al. 1993), the extent to which herbivory affects plant growth is debated. Herbivory may be detrimental to plant growth or cause plants to exhibit either compensatory or overcompensatory growth (McNaughton 1983).

Not as much research has been devoted to belowground herbivory, even though belowground herbivory may be more extensive than aboveground herbivory (Hole 1981, Andersen 1987). Belowground herbivory is important because more than 50% - 90% of net primary productivity is allocated to belowground plant parts (Andersen 1987). Also, there may be a greater biomass of subterranean animals than those that dwell above ground (Hole 1981). Belowground herbivory by insects reduces vegetation yields, the rate of nutrient and water uptake, and carbohydrate supply. How belowground herbivory affects yield is better documented than how it affects forage quality (Brown and Gange 1991).

The fossorial pocket gopher (Geomyidae) frequently invades alfalfa fields, reducing yields 17 - 46% (Case 1989). As gophers dig underground burrow systems, they cut and consume roots (Reichman and Smith 1985). They also consume aboveground vegetation by pulling it down into their tunnels or by feeding at the surface near their holes (Case and Jasch 1994). Soil mounds cover vegetation and provide germination sites for weeds (Reichman and Smith 1985, Martinsen et al. 1990). The weeds, in turn, decrease alfalfa yield and quality (Undersander 1991).

However, the burrowing and feeding behaviors of pocket gophers benefit soil and vegetation. Gophers bring soil to the surface where it is weathered and added to the topsoil

(Grinnell 1923). As gophers loosen soil, it becomes more porous and holds more water and oxygen. This facilitates roots in respiring, absorbing mineral ions, and penetrating the soil (Mielke 1977). Gophers increase the organic matter content of the soil by not eating all the food they cache and defecating underground (Grinnell 1923). This enhances soil structure, nutrient availability, and microorganism activity (Mielke 1977). As organic matter decomposes, chemical elements, especially carbon, nitrogen, phosphorous, and potassium, are rapidly liberated and become available to the plant (Ritter 1992).

My objective was to determine how gophers impacted the yields (Baker 1997) and forage quality of 2 varieties of alfalfa, Spredor 2 and Wrangler. Though Wrangler has higher yields (Hardman 1988), Spredor 2 has a more extensive creeping root system which may maintain its ability to absorb nutrients in the presence of gophers.

Predictions

On plots without gophers, I predicted that forage quality would be similar for Spredor 2 and Wrangler because they were grown in comparable conditions. I predicted that forage quality would be lower on plots with gophers than plots without gophers. However, because of Spredor 2's root system, I predicted that forage quality of Spredor 2 would decrease less than forage quality of Wrangler on plots with gophers versus plots without gophers.

STUDY AREA

The study area was located at the University of Nebraska Agricultural Research and Development Center, Section 6, Township 6 North, Range 8 East, Saunders County, east-central Nebraska. The area is characterized by flat to gently rolling terrain with temperate climate and moderate precipitation. Soils are primarily Filmore and Sharpsburg silty clay loams with 0 to 2% slope (Elder et al. 1965).

METHODS

I live-trapped plains pocket gophers from farms in Lancaster County. The trap, designed by Baker and Williams (1972) and modified by Jasch (1992), consisted of a 40 cm PVC pipe 9 cm in diameter. It was baited with carrots. Captured gophers were brought back to the lab, weighed, sexed, and tattooed for future identification. Because they are aggressive, each gopher was first anesthetized with 0.01 cc ketamine hydrochloride (Ketaset, 100 mg/ml) and 0.03 cc xylazine (Rompun, 20 mg/ml), as recommended by Jasch (1992). Tattooing involved injecting black India ink under the skin of toes (Bandoli 1987). Gophers were kept overnight to ensure recovery from anesthetization.

I released the gophers onto the alfalfa plots. To encourage it to dig, I placed each gopher in a 10 cm deep hole dug with a 1.2 l auger bucket 8 cm in diameter. To prevent the gophers from leaving and to protect them from predators, I encircled each gopher's hole with chicken wire for 1 to 2 weeks. Gopher activity was then monitored by the appearance of mounds. In each gopher plot, vegetation sampling was restricted to the area circumscribed by mounds. The number of mounds averaged 15 in each plot.

I sampled alfalfa at an early bloom stage prior to each harvest in 1995 and 1996. Five sites in each plot were randomly chosen. At each site, a 1.0 x 0.5 m^2 sampling frame was placed with the long axis oriented north-south (perpendicular to the rows). Rechargeable grass clippers were used to clip all vegetation rooted within this frame to a height of 2.5 cm. The frame was flipped once to the north and clipping was repeated to obtain a 1.0 m^2 sample. Weeds were separated from the alfalfa. Each of the 5 vegetation samples from each plot were placed in separate labeled paper bags and returned to the lab (Luce et al. 1981).

Only alfalfa from the first and third harvests were analyzed for forage quality. From each of the 5 alfalfa samples of each plot, I collected a grab sample (about 20 g). I composited these grab samples within each plot, dried them in a convection oven at 40 C, and ground them with a Wiley mill through 1-mm^2 mesh screen (Reuter et al. 1986). The samples were analyzed by the University of Nebraska's Soil and Plant Analytical Laboratory (SPAL). Energy dispersive x-ray fluorescence (Jones and Steyn 1973) was used to determine the quantities of Al, Ca, Cl, Cu, Fe, K, Mg, Mn, P, S, Si, and Zn. Near-infrared spectroscopy (Anderson and Mader 1994) was used to determine dry matter, crude protein, ADF, NDF, and RFV (Pathak and Jakhmola 1983, Walton 1983).

Prior to the third harvest each year, I took soil samples with a soil probe to a depth of 15 cm (6 inches) from 5 randomly chosen sites within each plot. I combined the 5 samples of each plot and sent to them to SPAL for determination of soil pH, organic matter, K, and Na in both 1995 and 1996 and additionally Ca, Cu, Fe, Mg, Mn, P, and Zn in 1995 (Peck and Melsted 1973). Since statistical accuracy is the same whether or not soil samples from a site are combined, or analyzed separately and then averaged, I chose to combine the samples before analysis to save on time and expenses (Peck and Melsted 1973).

Analysis

The study design was a split plot with the main units (alfalfa varieties) in a randomized complete block design. The site consisted of 9 paired fields (blocks) planted with alfalfa in August 1992. Half of each pair was planted with Spredor 2 and half with Wrangler. Each field of Spredor 2 and Wrangler was further divided in half and each half (referred to as a plot) (0.25 - 0.35 ha) was randomly assigned as gopher, which was stocked with gophers, and control, which was not stocked with gophers (Figure 1).

I used analysis of variance to detect significant differences (SAS Institute Inc. 1990). To increase power, I arithmetically combined 1995 and 1996 results in analysis and arithmetically combined first and third harvest results. If results were affected by how long (less than 1 year or 1 to 2 years) gophers had inhabited the plots, I analyzed the less-than -1-year plots separately from the 1-to-2-year plots.

RESULTS AND DISCUSSION

Gophers

I released 44 gophers onto the study site, but only 8 persisted. Prior to the first harvest in 1995, 4 gophers were successfully stocked on 2 blocks. Prior to the first harvest in 1996, another 4 gophers were successfully stocked on an additional 2 blocks. The other gophers either left the area or were killed by predators. Badger (*Taxidea taxus*) activity and possibly weasel (*Mustela* spp.) activity were seen on the study sites.

Fiber, protein, and RFV

The values for ADF, NDF, protein, and RFV (Tables 2 - 5) fell within average ranges for alfalfa (Table 1). On control plots, Wrangler and Spredor 2 differed from each other only in ADF and protein ($p \leq 0.06$) (Tables 2a and 4a). Spredor 2 had higher ADF, while Wrangler had higher protein. This may be due to genetic differences. The presence of gophers did not affect ADF, NDF, protein, or RFV of either alfalfa variety ($p \geq 0.12$).

Fiber and protein are affected by genetic differences, weather conditions, and maturity more so than root absorption (Pathak and Jakhmola 1983, Anderson and Mader 1994). Warmer weather favors higher fiber and cooler weather favors higher protein (Anderson and Mader 1994). Since the month (July) preceding the third harvest had 30% higher average temperature than the month (May) preceding the first harvest, I expected protein and RFV to be higher in the first harvest and ADF and NDF to be higher in the third harvest. However, unexpectedly, from third harvest compared to first harvest, protein was 5% higher ($p = 0.05$) (Table 4b) and ADF 9% lower ($p = 0.001$) (Table 2b) in Spredor 2 control plots. As expected, from first to third harvest, NDF increased by 3% ($p = 0.01$) (Table 3b) and RFV decreased by 6% ($p = 0.06$) (Table 5b) in Wrangler control plots. Since alfalfa was sampled at the same maturity and results did not follow expectations based on weather, genetic differences between the varieties must also influence results. The only harvest effects in the gopher plots were that from first to third harvest, protein decreased by 8% in Wrangler ($p = 0.007$) (Table 4b) and ADF decreased, as on the control plots, by 7% in Spredor 2 ($p = 0.03$) (Table 2b).

Alfalfa and soil minerals

Most notable of the results of the alfalfa mineral analysis was that in both Spredor 2 and Wrangler, Cu, Mn, and Zn decreased in gopher plots compared to control plots (Table 6). In Spredor 2 gopher plots, Cu decreased 15% ($p = 0.09$), Mn decreased 16% ($p = 0.08$), and Zn decreased 13% ($p = 0.0004$) over plots without gophers. In Wrangler gopher plots, Cu decreased 19% ($p = 0.05$), Mn decreased 19% ($p = 0.04$), and Zn decreased 13% ($p = 0.002$) over plots without gophers.

All minerals fell within expected ranges for alfalfa (Tables 1 and 6 and Appendix B). Si was lower than values reported by Howarth (1988). However, Si limits the digestibility of the feed, so lower Si is desired (Howarth 1988). On control plots, Mg was borderline (0.29 - 0.30%) between the critical (0.2 - 0.3%) and adequate (0.3 - 1.0%) ranges for normal alfalfa growth reported by Martin and Matocha (1973). In Wrangler, Mg was 14% ($p = 0.03$) lower on plots with gophers, placing it into the critical range (Martin and Matocha 1973). However, these Mg concentrations corresponded to average values for alfalfa reported by the National Research Council (1971).

Neither variety nor the presence of gophers affected Al, Fe, P, S, or Si ($p \geq 0.18$) (Appendix B). On control plots, varieties did not differ in any minerals except Ca ($p = 0.009$), K ($p = 0.07$), and Zn ($p = 0.09$) (Table 6). Since soils did not differ for Ca and Zn ($p \geq 0.93$) and levels in alfalfa were not correlated to soil concentrations ($p \geq 0.43$), these differences probably are genetic. However, soil and alfalfa concentrations of K were correlated ($p = 0.06$), indicating that K concentration in the soil influenced concentration in alfalfa. On gopher plots, varieties did not differ in any minerals except Ca ($p = 0.004$) and Mg ($p = 0.01$); in each case Spredor 2 had a higher concentration than Wrangler. Spredor 2 gopher plots had 31% higher Cl ($p = 0.05$) than Spredor 2 control plots.

Ca was the only mineral affected by how long the gophers were on the plots ($p \leq 0.01$) (Table 6). When gophers were present for less than 1 year, there were no variety ($p = 0.29$) or gopher ($p = 0.14$) effects on Ca content of alfalfa. When gophers were present for 1 to 2 years, Ca increased 7% in Spredor 2 ($p = 0.01$), but decreased 15% in Wrangler ($p = 0.002$) compared to control plots. On plots without gophers, Ca was 9% higher in Wrangler than in Spredor 2 ($p = 0.009$), while on plots with gophers, Ca was 16% higher in Spredor 2 than in Wrangler ($p = 0.004$).

Ca is important for cell wall and membrane formation and maintenance (Campbell 1990). Since Ca accumulates in vegetative tissues (Sumner and Boswell 1981), perhaps changes in concentrations of Ca do not become apparent unless the change is continued, which would explain why differences were not seen until gophers had been present for 1 to 2 years. The increase of Ca in Spredor 2 and decrease in Wrangler in the presence of gophers may be due to the differing root systems or it may be due to genetic differences in how Spredor 2 and Wrangler utilize or conserve Ca. Genetic differences in absorption of nutrients were demonstrated in soybean varieties. Harasoy 63 and Aoda have about the same absorption capacity, but at low nutrient levels, Harasoy 63 has the advantage because it has a more extensive root system. However, at high nutrient levels, Aoda can absorb twice as much as Harasoy 63 due to its genetic superior ability to uptake nutrients (Vose 1990).

Availability of nutrients for a plant is affected by nutrient supply in the soil and the plant's ability to take up nutrients (Corey and Schulte 1973). There were no significant differences between varieties or gopher treatments in soil minerals or chemistry (Appendix A). Concentrations of Mg in the alfalfa (Table 6) appeared to follow the same trends as its concentrations in the soil. However, soil and alfalfa concentrations were not correlated for Mg ($p = 0.37$). Differences in chemical composition of the alfalfa likely were more influenced by the alfalfa's ability to absorb nutrients than by differences in soil chemistry.

Minerals reach roots by diffusion through the soil solution, by water passively carrying them to the roots, and by roots growing toward the minerals (Salisbury and Ross 1992). Once at the root, minerals cross through membranes into cells by active transport or diffusion (Campbell 1990). Root depth, the number of deep roots versus the number of lateral spreading roots, the number of root hairs, and the numbers of branching, secondary, and tertiary roots greatly influence root function (Vose 1990). Because it can exploit more soil volume, a branched root system is more effective in absorbing nutrients than an unbranched system (Caradus 1990, Vose 1990). Absorption of specific nutrients differ with the physical characteristics of roots. The length and radius of roots have the greatest effect on P uptake. Ca, Fe, Mg, and Mn are absorbed by the youngest parts of the roots, but root age is unimportant for K or P absorption (Vose 1990). K and P are relatively immobile in the soil system, so increasing root size increases their absorption (Caradus

1990). Plants also vary in nutrient concentration due to metabolic differences, ability to translocate nutrients, differences in leaf content, and differences in accumulation of cations (Vose 1990). Genetics influence these mechanisms (Caradus 1990).

I predicted that the presence of gophers would decrease nutrient concentrations in both Wrangler and Spredor 2. As gophers damaged roots, the ability of the roots to absorb nutrients and the volume of roots would decrease. Of the nutrients affected by the presence of gophers, more nutrients decreased than increased and more nutrients decreased in Wrangler than in Spredor 2. I also predicted that in the presence of gophers, nutrient concentrations would decrease less in Spredor 2 than in Wrangler because Spredor 2 has a more extensive root system, providing greater root surface area for absorption. This only occurred for Ca concentration in alfalfa gophers inhabited for 1 to 2 years (variety*treatment $p = 0.002$). Genetic differences may influence results. I found no differences in root biomass between varieties or between treatments (Baker 1997). However, a close examination of root characteristics (branched verses unbranched, tap-rooted verses fibrous rooted, etc.) would better determine the extent results were influenced by gophers affecting the roots.

Because belowground herbivory primarily affects roots, while aboveground herbivory primarily affects aboveground vegetation, they influence forage quality differently. Georgiadis and McNaughton (1990) examined the effects of herbivory by cattle on forage quality of grasses. They determined that fiber was lower in areas of high herbivore use intensity than in areas of low herbivore use intensity regardless of study site or season. In her study of bison (*Bos bison*) and pronghorn (*Antilocapra americana*) foraging on prairie dog (*Cynomys ludovicianus*) towns, Krueger (1986) also found that shoot nitrogen (a component of crude protein) was higher where foraging pressure was the greatest. Thus, as aboveground herbivores consume vegetation, they maintain the vegetation in a younger stage of maturity in which concentration of fiber is lower and protein is higher (Church 1979).

Belowground herbivores, on the other hand, directly impact roots. This could have a greater role in altering mineral absorption than in altering fiber or protein. Georgiadis and McNaughton (1990) found that concentrations of Ca, K, Mg, Mo, and Na of grasses increased with increasing aboveground herbivore use intensity, but that site and season influenced mineral content more so than herbivore use intensity. I found that the presence of gophers influenced mineral content more so than fiber or protein. One must also consider the indirect effects of belowground herbivores. The presence of gophers increases weeds which in turn lower forage quality (Undersander et al. 1991). Root damage by belowground herbivores could harm plants by providing a site for pathogen entrance (Manglitz and Ratcliffe 1988, Brown and Gange 1991).

CONCLUSION

Presence of gophers did not impact alfalfa forage quality as greatly as I predicted. Presence of gophers did not affect ADF, NDF, protein, or RFV of either variety. Gopher presence affected only 6 of the 12 minerals examined. I was able to stock only 4 blocks with a total of 8 gophers. Perhaps if I had been able to establish more gophers on the study site, greater differences in the data would have been detected. Even so, statistical differences do not imply biological differences since the examined variables fell within ranges expected for normal alfalfa growth. The variables that I used to check forage quality indicated that there were no substantial differences between varieties or due to belowground herbivory by pocket gophers.

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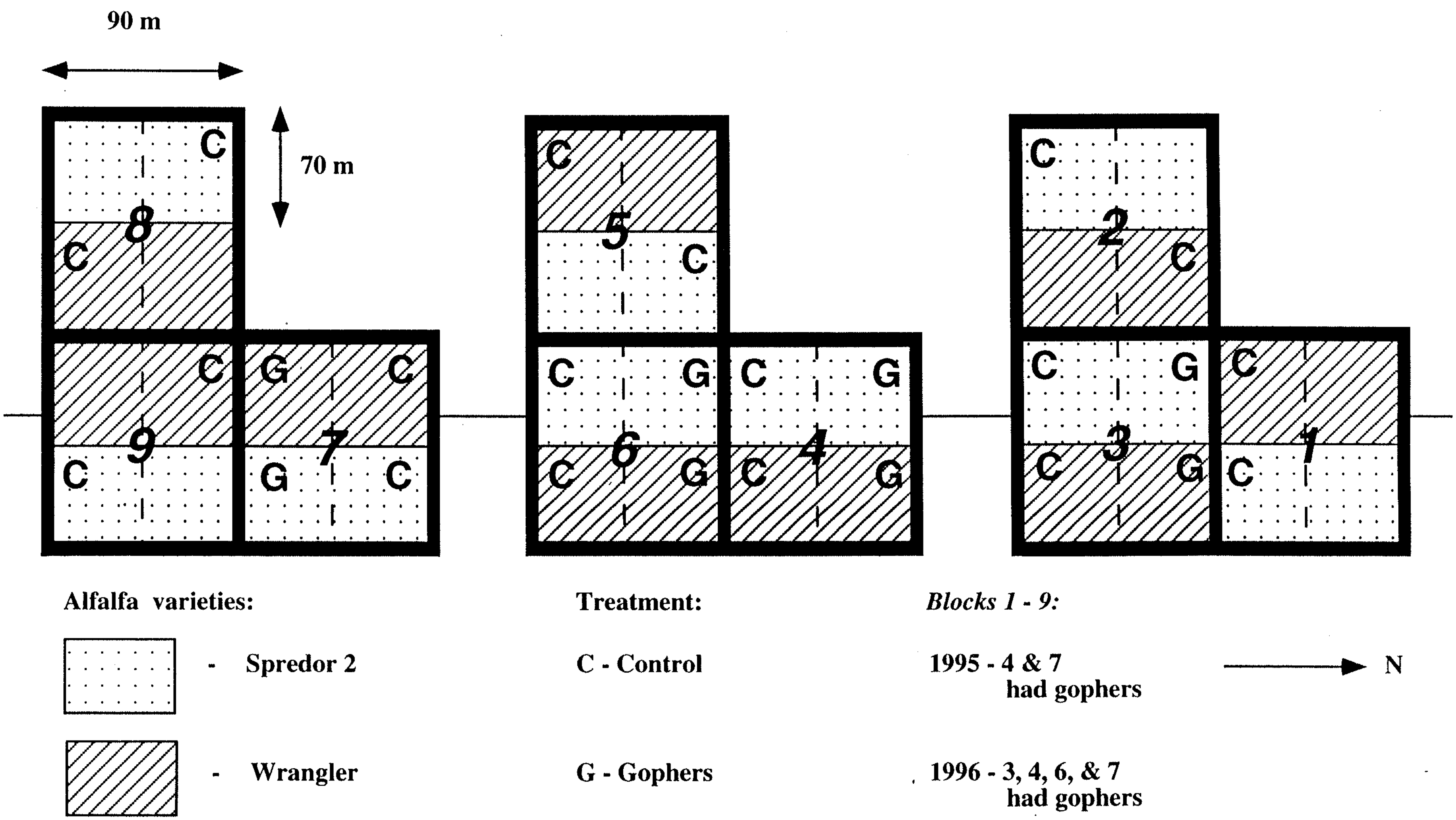

Fig. 1. Study site at the University of Nebraska Agricultural Research and Development Center, Saunders County, Nebraska.

Table 1. Ranges of various forage quality factors and elements expected for alfalfa (Natl. Res. Counc. 1971, Martin and Matocha 1973, Mader and Rush 1984, Howarth 1988, Anderson and Mader 1994).

Factor	Range	Explanation
ADF %	< 31	for high producing dairy cattle
	41 - 42	for maintenance of beef or dry dairy cattle
NDF %	< 40	for high producing dairy cattle
	54 - 60	for maintenance of beef or dry dairy cattle
Protein %	18 - 20	found in early bloom stage of alfalfa
	20 - 24	found in immature stage of alfalfa
RFV	> 151	for high producing dairy cattle
	87 - 102	for maintenance of beef or dry dairy cattle
Ca %	1.8 - 2.2	found in normal alfalfa yields
Cu ppm	7 - 30	found in normal alfalfa yields
Fe ppm	50 - 200	found in normal alfalfa yields
K %	> 2	found in normal alfalfa yields
Mg %	0.20 - 0.30	in alfalfa, results in 10 - 20% lower yields
	0.30 - 1.00	found in normal alfalfa yields
	0.19 - 0.25	found in immature to pre-bloom alfalfa
Mn ppm	20 - 100	found in normal alfalfa yields
P %	0.24 - 0.40	found in normal alfalfa yields
S %	0.25 - 0.30	found in normal alfalfa yields
	0.40	toxic level in alfalfa, resulting in 0 - 30% lower yields
Si %	0.68 - 0.95	found in alfalfa
Zn ppm	21 - 70	found in normal alfalfa yields

Table 2a. Acid detergent fiber (%) of Wrangler (W) and Spredor 2 (S) alfalfa in control plots (C) and plots with gophers (G).

Comparison	Control		Gophers		p
	$\bar{x}$	SE	$\bar{x}$	SE	p
Wrangler	28.63	0.44	28.83	0.48	0.75
Spredor 2	29.67	0.56	29.55	0.53	0.96
WC*SC					0.06
WG*SG					0.19

Table 2b. Acid detergent fiber (%) of Wrangler (W) and Spredor 2 (S) alfalfa in control (C) plots and plots with gophers (G), by harvest.

Comparison	Harvest 1		Harvest 3		p
	$\bar{x}$	SE	$\bar{x}$	SE	p
WC	28.90	0.79	28.36	0.46	0.47
WG	28.27	0.76	29.39	0.40	0.22
SC	30.98	0.64	28.24	0.62	0.001
SG	30.62	0.76	28.54	0.74	0.03

Table 3a. Neutral detergent fiber (%) of Wrangler (W) and Spredor 2 (S) alfalfa in control plots (C) and plots with gophers (G).

	Control		Gophers		
Comparison	$\bar{x}$	SE	$\bar{x}$	SE	p
Wrangler	33.83	0.61	33.33	0.77	0.65
Spredor 2	34.08	0.72	34.15	0.84	0.95
WC*SC					0.80
WG*SG					0.49

Table 3b. Neutral detergent fiber (%) of Wrangler (W) and Spredor 2 (S) alfalfa in control (C) plots and plots with gophers (G), by harvest.

	Harvest 1		Harvest 3		
Comparison	$\bar{x}$	SE	$\bar{x}$	SE	p
WC	32.58	0.64	35.09	0.85	0.01
WG	32.60	0.52	34.06	1.35	0.21
SC	34.17	0.76	33.98	1.27	0.84
SG	33.50	0.51	34.81	1.54	0.26

Table 4a. Protein (%) of Wrangler (W) and Spredor 2 (S) alfalfa in control plots (C) and plots with gophers (G).

	Control		Gophers		
Comparison	$\bar{x}$	SE	$\bar{x}$	SE	p
Wrangler	24.44	0.28	23.76	0.41	0.12
Spredor 2	23.74	0.25	23.62	0.24	0.77
WC*SC					0.05
WG*SG					0.72

Table 4b. Protein (%) of Wrangler (W) and Spredor 2 (S) alfalfa in control (C) plots and plots with gophers (G), by harvest.

	Harvest 1		Harvest 3		
Comparison	$\bar{x}$	SE	$\bar{x}$	SE	p
WC	24.67	0.35	24.22	0.43	0.39
WG	24.69	0.31	22.83	0.44	0.007
SC	23.21	0.15	24.27	0.40	0.05
SG	23.20	0.28	24.05	0.38	0.19

Table 5a. Relative feed value of Wrangler (W) and Spredor 2 (S) alfalfa in control plots (C) and plots with gophers (G).

	Control		Gophers		
Comparison	$\bar{x}$	SE	$\bar{x}$	SE	p
Wrangler	184.07	3.66	185.89	4.26	0.80
Spredor 2	181.20	4.88	180.81	4.75	0.96
WC*SC					0.66
WG*SG					0.52

Table 5b. Relative feed value of Wrangler (W) and Spredor 2 (S) alfalfa in control plots (C) and plots with gophers (G), by harvest.

	Harvest 1		Harvest 3		
Comparison	$\bar{x}$	SE	$\bar{x}$	SE	p
WC	190.20	4.75	177.93	4.90	0.06
WG	190.49	2.36	181.29	7.35	0.23
SC	177.04	4.81	185.37	8.60	0.18
SG	181.01	2.42	180.61	9.41	0.96

Table 6. Elements (% or ppm) found in Wrangler (W) and Spredor 2 (S) alfalfa in control plots (C) and plots with gophers (G).

	Wrangler					Spredor 2						
	Control		Gopher			Control		Gopher			WC*SC	WG*SG
Element	$\bar{x}$	SE	$\bar{x}$	SE	p	$\bar{x}$	SE	$\bar{x}$	SE	p	p	p
Ca % (gophers present < 1 year)	2.13	0.11	2.11	0.13	0.67	2.05	0.13	1.98	0.09	0.28	0.29	0.14
Ca % (gophers present 1 - 2 years)	2.27	0.12	1.93	0.06	0.002	2.08	0.05	2.23	0.05	0.01	0.009	0.004
Cl %	0.15	0.03	0.16	0.04	0.47	0.13	0.03	0.17	0.04	0.05	0.62	0.71
Cu ppm	11.41	0.71	9.27	0.69	0.05	11.67	0.74	9.87	0.65	0.09	0.75	0.55
K %	2.98	0.07	3.01	0.09	0.54	3.06	0.07	3.05	0.09	0.95	0.07	0.38
Mg %	0.29	0.01	0.25	0.01	0.03	0.30	0.02	0.29	0.01	0.44	0.38	0.01
Mn ppm	58.48	3.71	47.46	3.67	0.04	58.22	5.88	49.16	4.27	0.08	0.94	0.70
Zn ppm	25.85	0.69	23.11	0.69	0.002	27.18	0.70	23.56	0.57	0.0004	0.09	0.60

Appendix A. Chemical analysis of soil found in Wrangler (W) and Spredor 2 (S) alfalfa control plots (C) and plots with gophers (G).

	Wrangler					Spredor 2						
	Control		Gopher			Control		Gopher			WC*SC	WG*SG
Element	$\bar{x}$	SE	$\bar{x}$	SE	p	$\bar{x}$	SE	$\bar{x}$	SE	p	p	p
Organic matter %	3.08	0.15	3.27	0.08	0.38	3.31	0.14	3.37	0.15	0.75	0.19	0.59
pH	6.41	0.12	6.52	0.14	0.54	6.31	0.14	6.38	0.16	0.68	0.51	0.47
Ca mol/kg	13.85	2.25	15.00	0.30	0.47	13.80	1.57	15.65	1.57	0.29	0.97	0.67
Cu ppm	0.60	0.04	0.55	0.06	0.79	0.61	0.10	0.66	0.10	0.81	0.95	0.48
Fe ppm	41.55	21.45	36.15	12.35	0.90	42.00	18.70	42.10	18.70	1.00	0.99	0.84
K ppm	328.2	18.23	374.9	13.63	0.18	308.8	33.96	340.1	37.13	0.35	0.52	0.34
K mol/kg	1.04	0.16	1.18	0.13	0.35	0.89	0.14	0.92	0.14	0.82	0.25	0.10
Mg mol/kg	2.26	0.13	2.04	0.16	0.46	2.37	0.15	2.30	0.15	0.81	0.68	0.37
Mn ppm	21.90	4.70	21.15	0.45	0.94	22.65	4.68	22.25	4.68	0.97	0.92	0.88
Na mol/kg	0		0			0		0				
P ppm	22.37	4.30	29.98	5.52	0.15	25.00	5.93	25.26	6.34	0.96	0.55	0.38
Zn ppm	0.89	0.30	0.92	0.10	0.95	0.86	0.22	0.95	0.22	0.82	0.93	0.94

Appendix B. Elements (% or ppm) found in Wrangler (W) and Spredor 2 (S) alfalfa in control plots (C) and plots with gophers (G).

	Wrangler					Spredor 2						
	Control		Gopher			Control		Gopher			WC*SC	WG*SG
Element	$\bar{x}$	SE	$\bar{x}$	SE	p	$\bar{x}$	SE	$\bar{x}$	SE	p	p	p
Al %	0.06	0.01	0.05	0.01	0.24	0.07	0.02	0.07	0.02	0.75	0.62	0.25
Fe ppm	328.0	54.52	257.0	57.41	0.34	353.6	90.86	336.0	88.38	0.81	0.69	0.32
P %	0.29	0.01	0.30	0.02	0.42	0.29	0.01	0.29	0.01	0.66	0.91	0.18
S %	0.32	0.01	0.31	0.02	0.50	0.31	0.01	0.32	0.01	0.43	0.31	0.67
Si %	0.41	0.07	0.34	0.08	0.41	0.46	0.11	0.43	0.11	0.77	0.57	0.36